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RESEARCH DEPARTMENT

REPORT

A highly-directional aerial for re-broadcast reception of v.h.f. television signals

No. 1969/21

Research Department, Engineering Division
THE BRITISH BROADCASTING CORPORATION

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D. Maurice

D.J. Whythe, B.Sc.(Eng.), C.Eng., M.I.E.E.

Head of Research Department

(RA-40)

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SUMMARY

*A highly-directional aerial for re-broadcast reception of the North Hessary Tor (*Devon*) signal on Channel 2 has been designed and installed at Torteval (Guernsey). The aerial is novel in that it provides a null-slewing facility which can be adjusted by the station staff for minimum interference.*

Reports received during the first six months of its service show that the aerial has been used by the station staff, in preference to all other available aerials, for more than 99% of the time, and that interference of all kinds should be reduced by about 120 programme hours per annum.

1. INTRODUCTION

The Band I television service to the Channel Islands is broadcast in Channel 4 from a transmitter at Les Platons (Jersey). For its source of television programme the transmitter relies principally upon direct reception of the signals broadcast from North Hessary Tor (Channel 2) on the mainland. The signals are received at Torteval (Guernsey) and relayed by s.h.f. link to Les Platons.

With the expansion of v.h.f. television broadcasting on the continent, reception at Torteval suffers from steadily increasing co-channel interference. Although the interference occurs for only a small percentage of the total programme time, it usually continues for several hours, or sometimes days on end when propagation conditions become favourable. Facilities which existed at Torteval for selecting aerials receiving North Hessary Tor, Wenvoe or Rowridge (or for receiving the North Hessary Tor signals directly at Les Platons) had become inadequate to protect the service.

Experiments performed to study diversity reception of North Hessary Tor showed that two receiving points on Guernsey would require to be spaced some 5 km apart at least in order to give significant improvement. Frequency diversity (e.g. reception of either North Hessary Tor or Rowridge) would have given greater benefit but it was ruled out because the programmes radiated from the two stations differ at certain times of the day.

To improve the service as much as possible, it was decided to provide a special aerial to receive the North Hessary Tor signal and to design it to have nulls or very low sidelobe levels along the bearings of all existing (and possible future) co-channel stations. For reasons of field strength, local topography, and the need to retain reserve aerial facilities, it was desirable to site this new aerial at Torteval and to continue using the s.h.f. link to Les Platons.

This report describes the design and setting-up of the new aerial, and its subsequent performance in service.

2. THE AERIAL

2.1. General Requirements

The median field strength at Torteval from North Hessary Tor is about 0·5 mV/m (vertically polarized) at 23 m above ground level. The site forms part of a fairly level region, about 68 m above ordnance datum, extending about 500 m to the coastline. Site surveys had shown that little could be gained by mounting receiving aerials higher than 25 m above ground level.

The bearing of North Hessary Tor from Torteval is 322° ETN, and nearly all the co-channel stations lie on bearings within the arc 0° to 180° ETN. Some stations are sited close enough to interfere continuously (e.g. Caen and, to a lesser extent, Holme Moss) whilst others cause interference only when either tropospheric or ionospheric conditions are favourable. Interference from stations within the range of tropospheric propagation (about 700 km) is likely to be fairly frequent and, at times, severe; interference from stations at greater ranges up to 2,500 km occurs only under sporadic-E ionospheric conditions, and is likely to be infrequent but very severe.

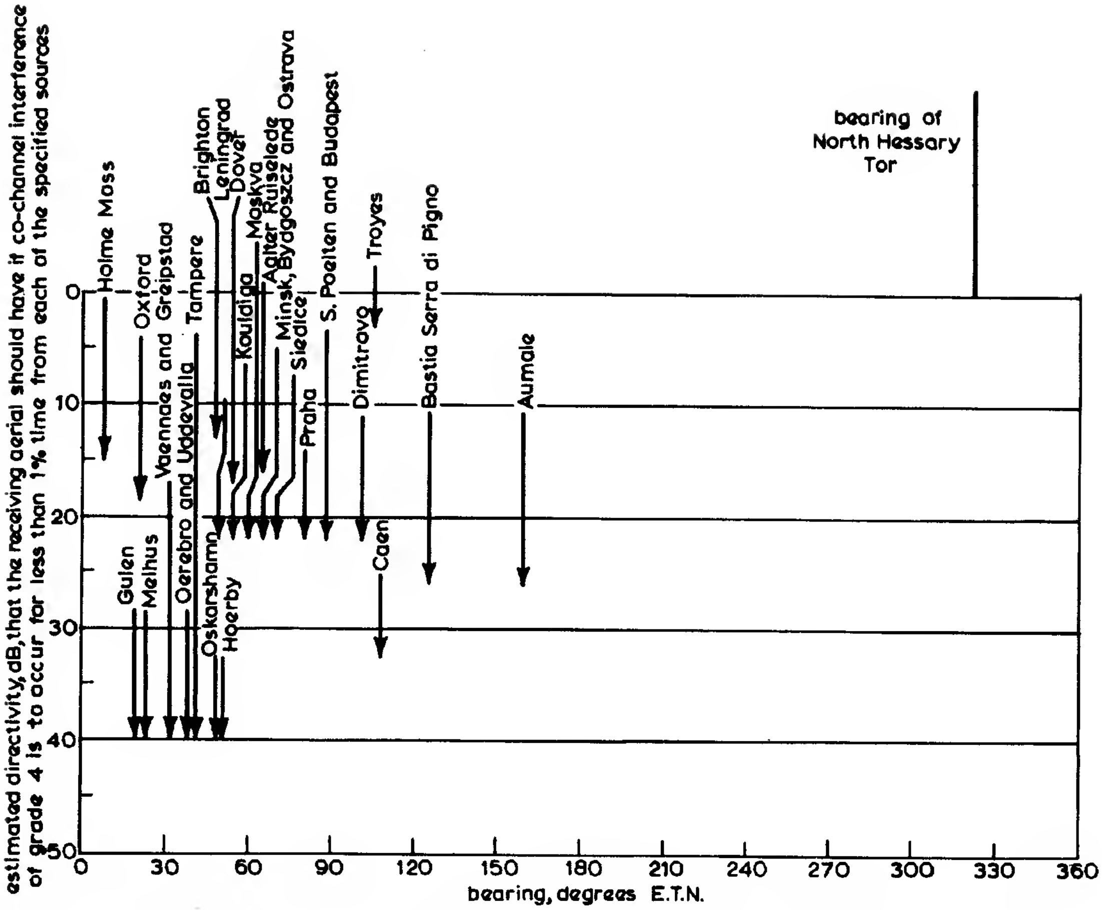

Fig. 1 - Estimated directivity required in respect of known co-channel interference sources acting alone

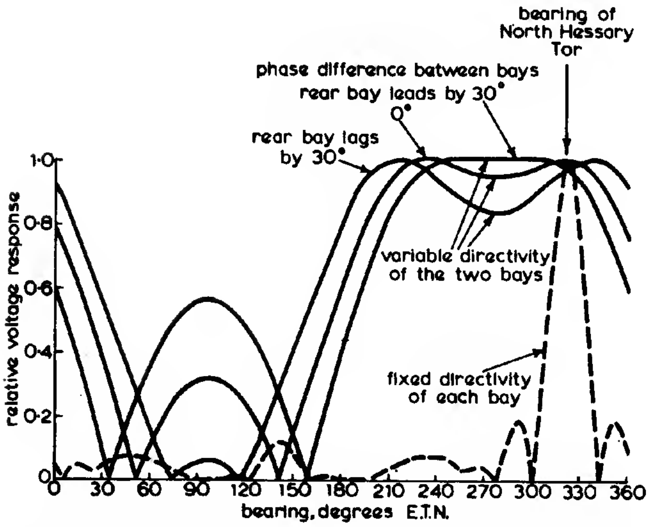

Fig. 2 - Fixed directivity of each bay and variable directivity of the two bays

An indication of the overall directivity required is given in Fig. 1 which shows the estimated suppression required for individual interfering stations. Stations requiring extreme suppression (i.e. 40 dB) interfere only on occasions when sporadic-E propagation conditions are present, when the interference can be intense.

The general requirement, therefore, was for an aerial with moderately high gain and with very low sidelobe levels over the arc 38° to 118° (relative to the bearing of the main lobe) which could be mounted at about 20 – 25 m above ground level.

2.2. Aerial Design

It was decided to adopt a two-bay aerial, each bay comprising three double three-element Yagis. The feeds to the two bays could be varied in amplitude and phase so that the position of two nulls in the overall pattern could be varied over a fairly wide range of bearings, without altering the positions of the other nulls and without greatly affecting the amplitude of the wanted signal. The gain of such an aerial is about 15 dB. The effect of the null slew is shown in Figs. 2 and 3. Fig. 2 shows both the fixed directivity of each bay and the variable directivity of the two bays; the overall directivity is the product of the two. By de-phasing the feeds to the bays by ±30°, the two variable nulls are both moved in opposite directions over an arc of about 40° whilst changing the amplitude of the wanted signal by less than 0·4 dB. Fig. 3 shows these ranges of bearings in relation to the geographical situation of Torteval and of the nearer interfering stations.

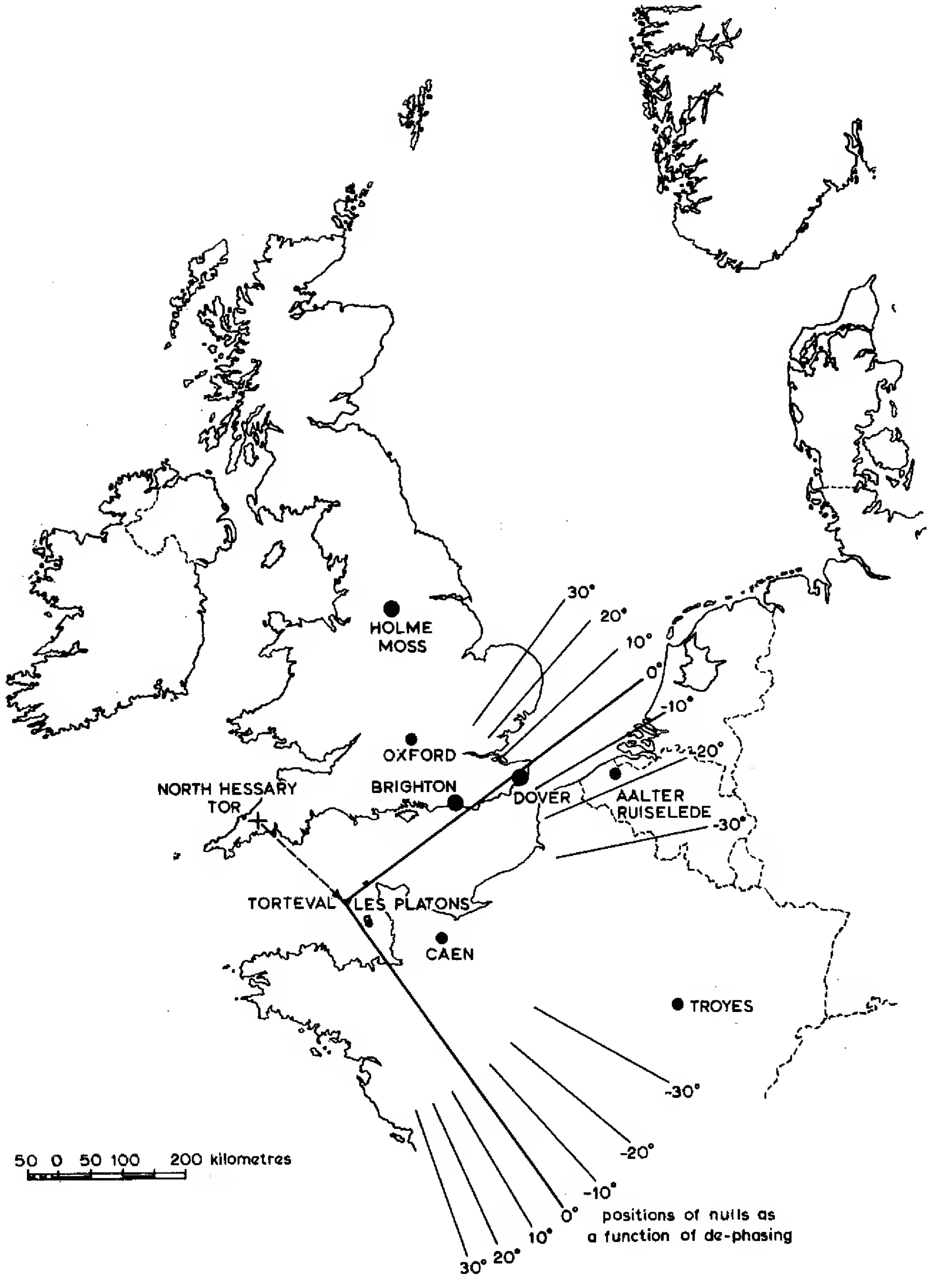

Fig. 3 - Null-slewing facility of the new array

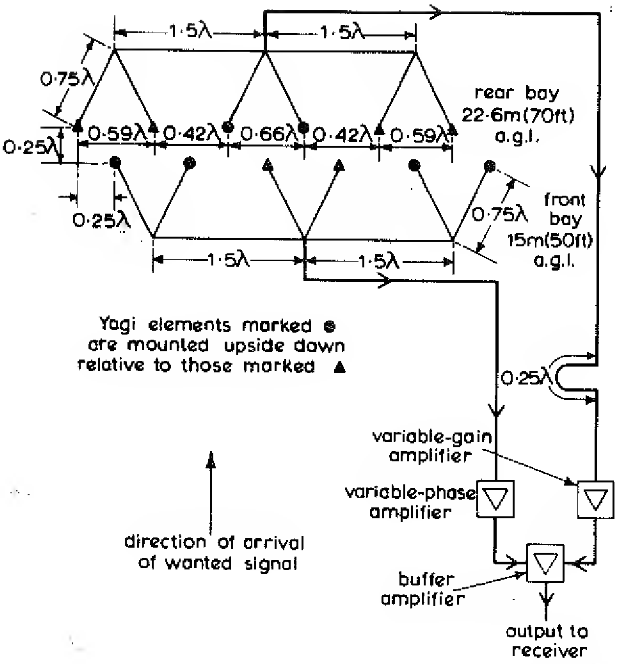

Fig. 4 - Element separations and feeder arrangements

The optimum separations between the Yagis in each bay were decided by model measurements (see Section 2.3); Fig. 4 shows the separations finally adopted, and the branch feeder arrangements. The branch feeder lengths were chosen so as to achieve substantially equal feed currents to all the Yagis. The method adopted for achieving the quadrature feed to the two bays (shown in Fig. 4) was chosen so that the two nulls associated with the pair of bays would not vary with frequency. In the final aerial the rear bay was mounted well above the forward bay; the signals received in the two bays therefore differed in amplitude as a result of their different height gains. This was allowed for by adjustment on site when setting up the aerial, as described in Section 3.1.

2.3. Model Measurements

Horizontal radiation pattern (h.r.p.) measurements of one bay* were made on a one-eighth scale model in the frequency range 384 – 416 MHz (corresponding to 48 – 52 MHz at full scale). These measurements enabled the separations between the Yagis of one bay to be optimized in the presence of mutual couplings. It was not necessary to model the complete array of two bays because their relative positions were such as to ensure that the mutual coupling between bays was small.

* This work was carried out by Mr. D.G. Evans of Transmitter Department.

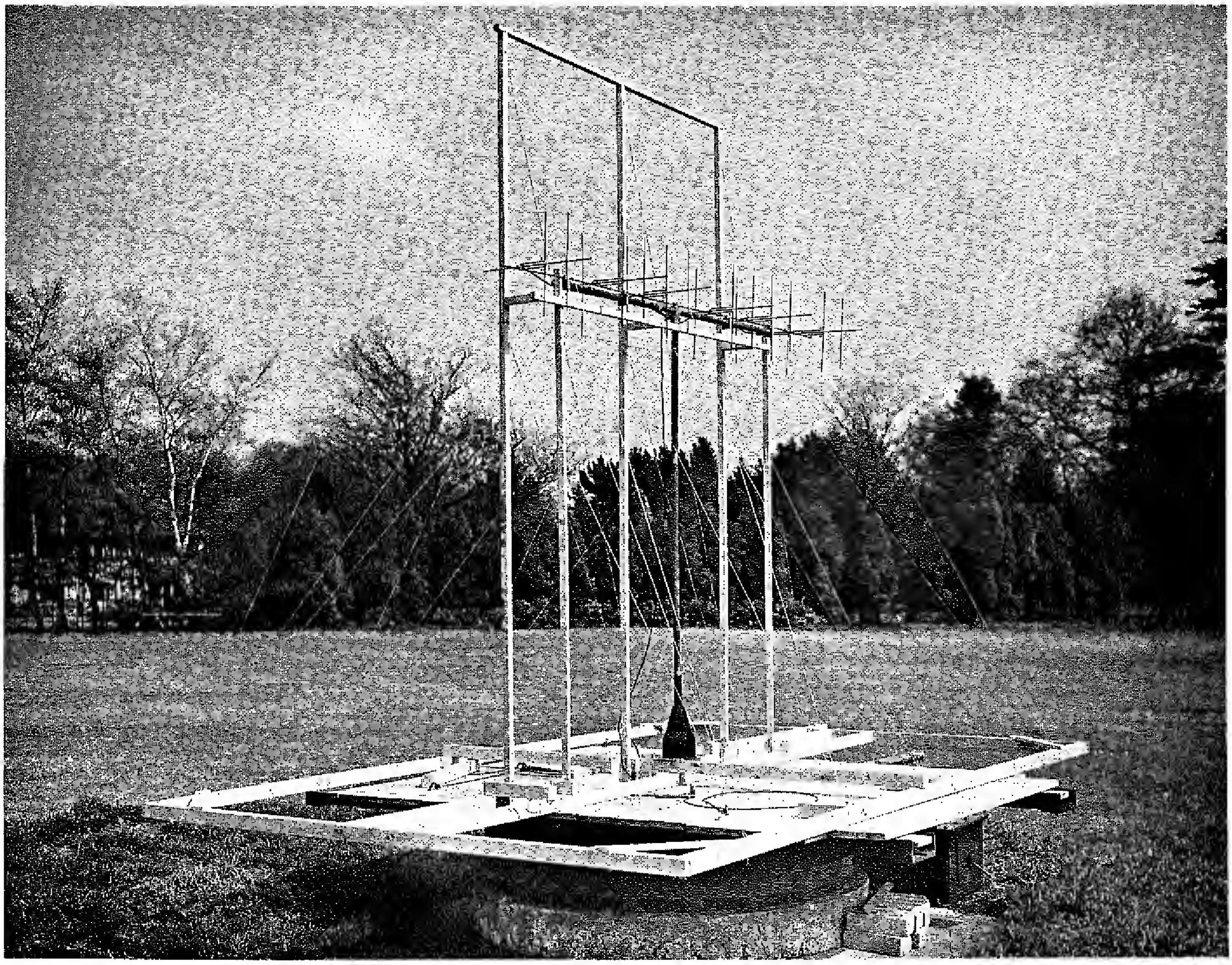

Fig. 5 - Model of one bay, with conducting stays

The model Yagis were designed so that they could be reproduced in detail at full scale, ensuring equal performance in the final aerial. The impedance characteristic of the whole aerial was not known exactly but it was unimportant because the combining amplifiers (see Section 2.4) were designed to have an input impedance matching the main feeders.

The full-scale aerial was to be supported on stayed poles. The effect of conducting stays was therefore also investigated as part of the model measurements, using the arrangement shown in Fig. 5. It was found that the lower stays could be conducting without detriment to the aerial directivity but that if the upper stays were conducting they completely upset the radiation pattern of the lower bay. It was later found possible to make all stays on the full-scale aerial of non-conducting material in the region of both bays of the aerial (see Section 3.1).

The directivity of one model bay (with the inter-Yagi spacings shown in Fig. 4) measured at 400 MHz (corresponding to 50 MHz at full scale), is shown in Fig. 6.

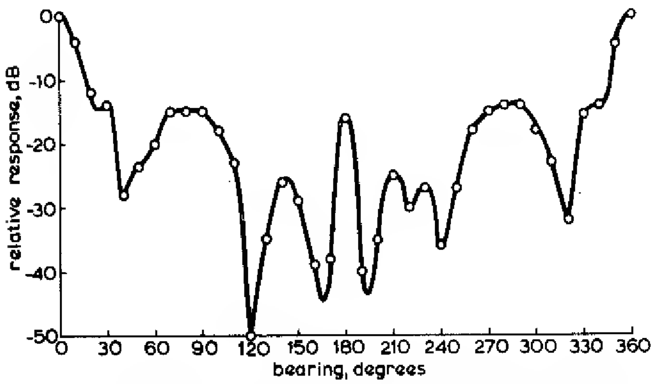

Fig. 6 - Horizontal directivity of one model bay: measured, without stays, at 400 MHz

2.4. Combining Amplifiers

The five combining amplifiers, described in the Appendix, comprise a pair of pre-amplifiers, an amplifier which enables the phase of the signal to be varied (without varying its amplitude), an amplifier which enables the amplitude of the signal to be varied (without varying its phase), and a buffer amplifier. These amplifiers were connected as shown in Fig. 7. The pre-amplifiers were designed to have an input impedance matching the main feeders, and to have a good noise factor. The variable-gain and variable-phase amplifiers were designed to be as similar as possible so as to have equal group delays. The amplitude and phase adjustments were arranged on separate controls, each with a high-resolution dial so that the settings for a given condition could be accurately logged and repeated. Later experience showed that this may not be the most convenient arrangement for use under fading conditions (see Section 3.2).

The complete amplifier assembly is shown in Fig. 8.

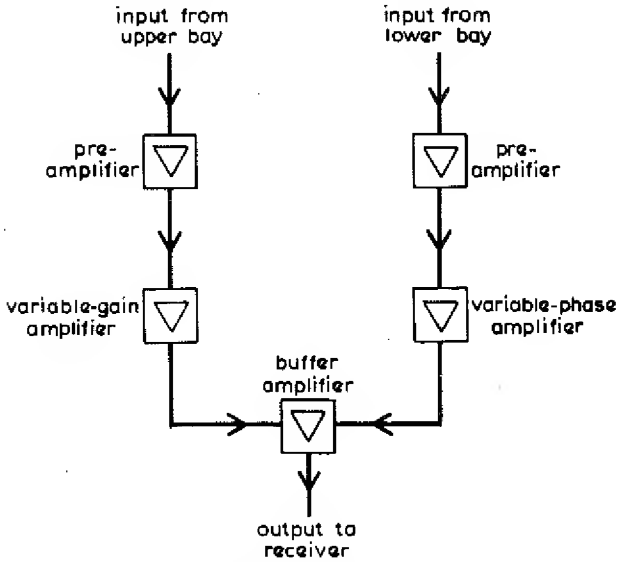

Fig. 7 - Schematic of amplifier arrangement

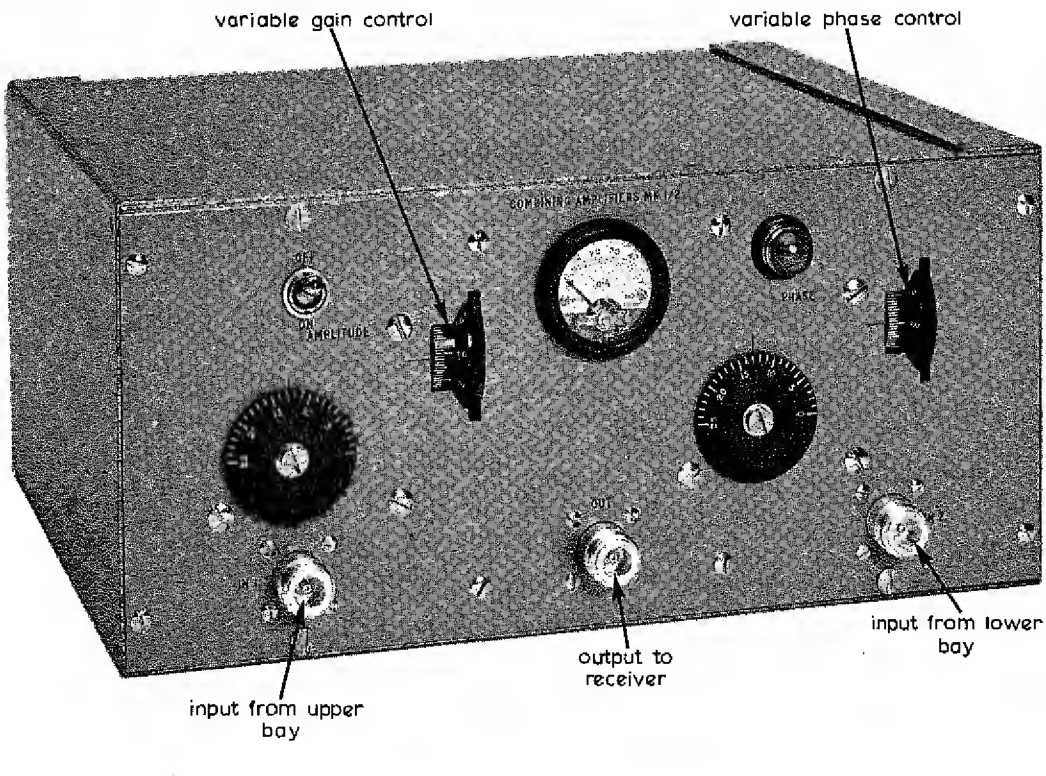

Fig. 8
The combining amplifiers

3. AERIAL PERFORMANCE AT FULL SCALE

3.1. Performance during Installation

The site plan (Fig. 9) shows the situation of the new aerial in relation to the other aerials on the site.

The two bays of the aerial were mounted on six wooden poles, at 15 m and 22·6 m above ground level as shown in Fig. 10. The poles were supported by Terylene stays. The combining amplifiers were housed in the building and connected to the two bays with UR57 (75Ω) cable. The aerial was set up initially by temporarily connecting a λ/2 cable in the feed from each bay in turn and adjusting the controls on the combining amplifiers for minimum received signal from North Hessary Tor. It was found that, with the controls at their optimum settings, the depth of null varied cyclically over the range −35 to −40 dB with about 5 to 10 seconds period. A similar effect was observed later when c.w. test signals (horizontally or vertically polarized) were radiated at 50 MHz towards the array, from a range of about 3 km, along various bearings from the side and rear of the array. As expected, it was found that, for best rejection of the test signals, the settings of the controls were similar to those which had been found to give best reception of the North Hessary Tor signal but the residual level of the test signals varied cyclically with about 1 second period; both the period and the range of variation depended upon the bearing of the test signal. Similar variations had been observed, from other aerials on the site, on long-distance interfering signals. The reason for these cyclic variations is not known but they may have been caused by back-scatter from the sea swell.[1] The effect was later found to be unimportant but it does set a limit of about −35 dB, in some directions, to the directivity of the aerial.

The aerial performance was finally checked on test signals from North Hessary Tor and found satisfactory with regard to pulse and bar response and signal/noise ratio. Tests in which c.w. interference was radiated at 50 MHz from test locations similar to those above, whilst receiving the North Hessary Tor trade-test signal, showed the directivity of the aerial to be superior to that of all other receiving aerials on the site.

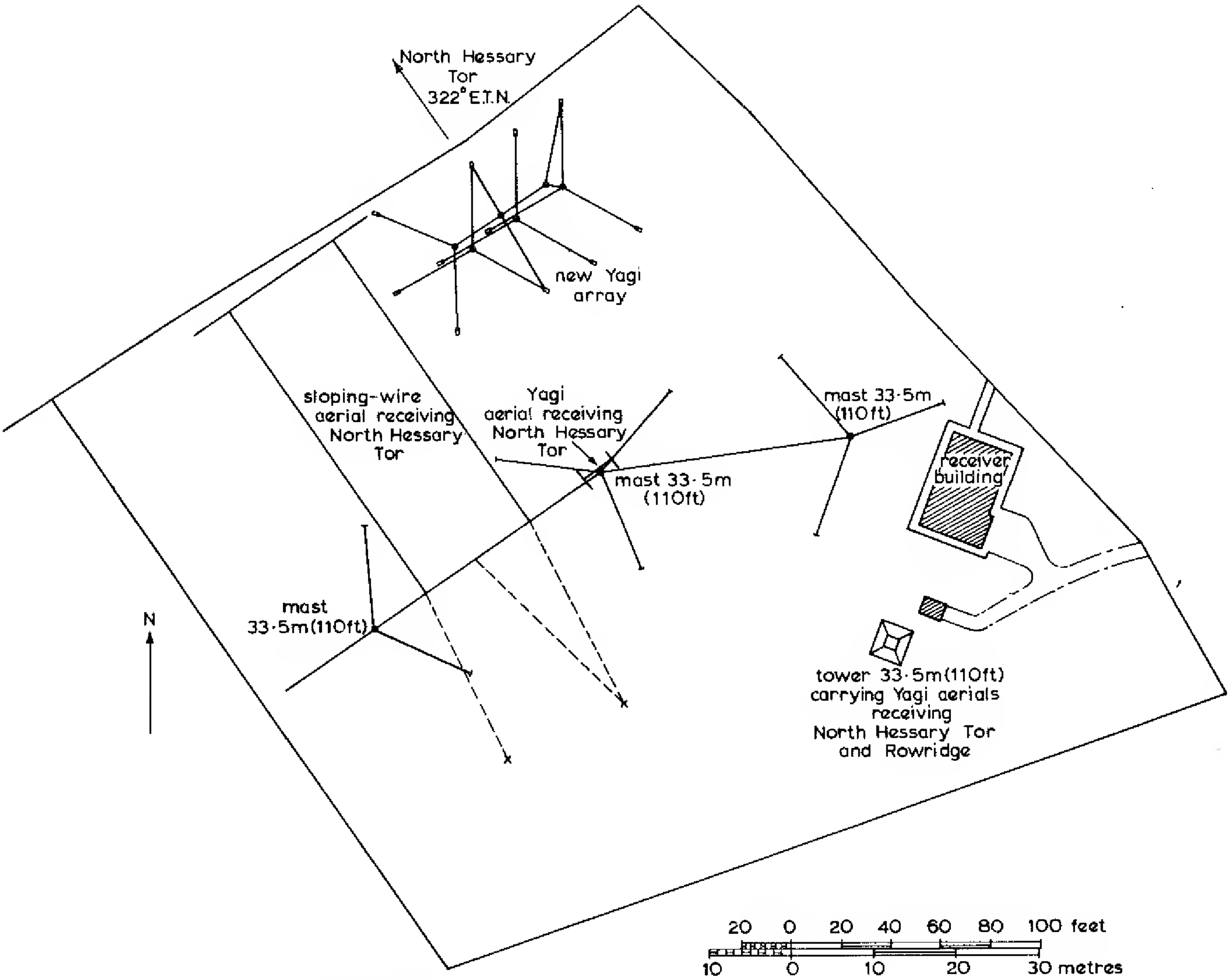

Fig. 9 - Site plan of Torteval receiving station

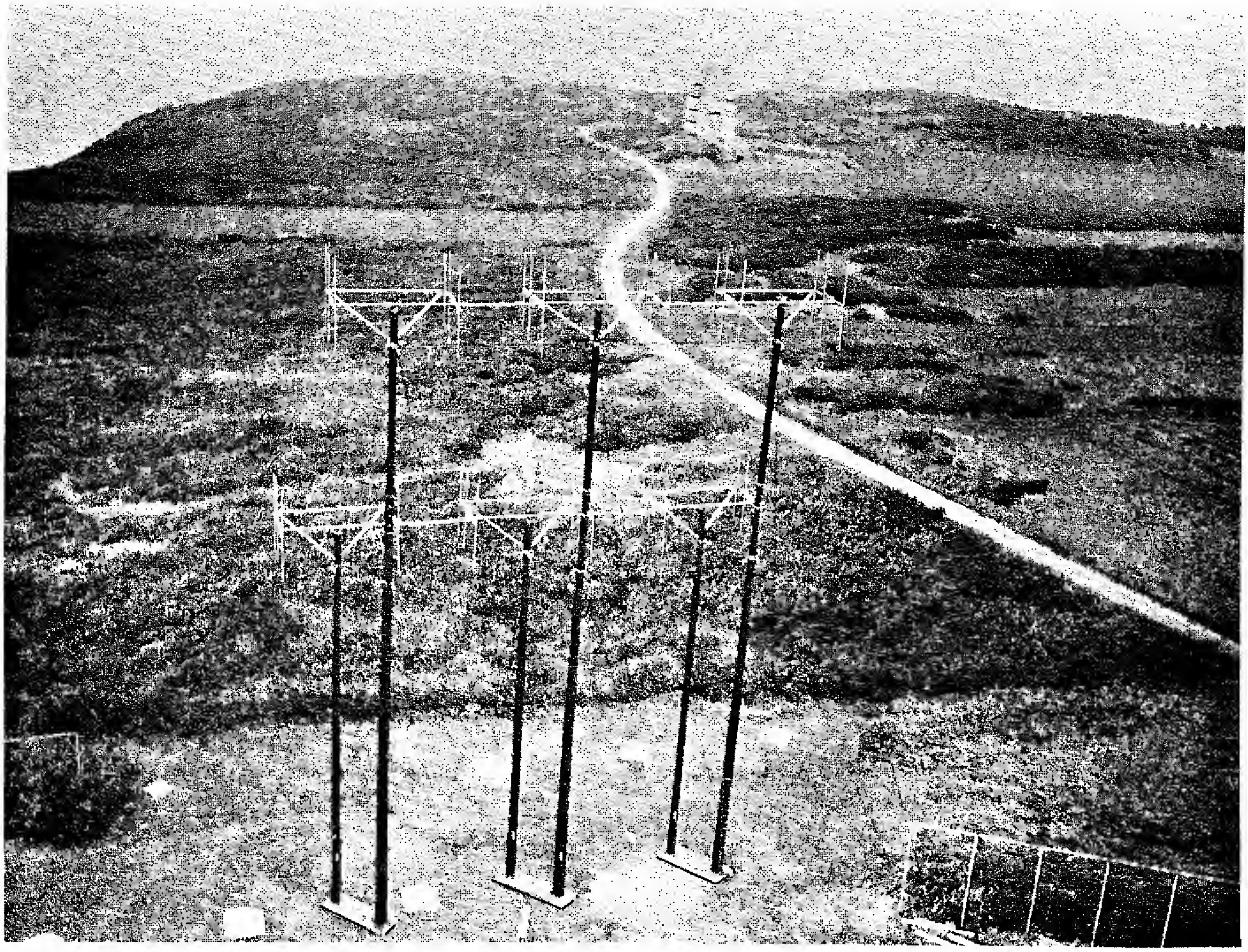

Fig. 10 - The full-scale array

3.2. Performance in Service

The aerial was put into service in January 1968 and its performance is being compared, under service conditions by the stations staff at Les Platons, with that of other aerials. The comparison is expected to continue for at least a twelve-month period but the following results apply over the first six-month period April to September 1968. This is the time of year when co-channel interference is generally most severe.

The test was conducted by feeding the outputs from the new Yagi array and from one other chosen aerial at Torteval by s.h.f. link to Les Platons. The other aerials at Torteval from which this choice could be made were:

Aerial (a) Double three-element Yagi on 33 m tower, fully protected against precipitation-static interference,[2] receiving the North Hessary Tor signal.

Aerial (b) Double three-element Yagi on 33 m stayed pole, receiving the North Hessary Tor signal.

Aerial (c) Double three-element Yagi on 33 m tower, receiving the Rowridge signal.

Aerial (d) Two-bay sloping-wire aerial receiving the North Hessary Tor signal (this aerial was removed during the latter part of the test period because it was never found to give the best alternative signal. This aerial is therefore disregarded).

Facilities already existed by which the Les Platons staff could select either aerial (c) or whichever of aerials (a), (b) or (d) the engineer at Torteval judged would give the best result under the prevailing conditions. In addition, the signal from a double three-element Yagi at Les Platons (receiving North Hessary Tor) could be selected if necessary.

The comparison was made at Les Platons between the signal from the new Yagi array on the one hand and the best alternative signal on the other. It was therefore a severe comparison because the new array was compared at all times with whichever other aerial was giving the best result under the particular conditions. The provisional results for the first six months of the tests, covering 2004 hours of programme time, are given below.

Table 1 shows the usage of the various aerials for service chosen by the station staff as giving the best received signal at the time.

TABLE 1

Aerial Usage for Programme Feed

Aerial	Total number of hours in service
New Yagi array	1,988·3
Aerial (a)	0·7
Aerial (b)	4·1
Aerial (c)	9·9
Yagi aerial at Les Platons	1·0

Aerial (c) and the Yagi aerial at Les Platons were used only when deep fades precluded the use of North Hessary Tor as a source of programme from any aerial at Torteval.

The degradation to the signal radiated from Les Platons was also assessed subjectively by the station staff according to the following scale:

1. Imperceptible
2. Just perceptible
3. Definitely perceptible (but not disturbing)
4. Somewhat objectionable
5. Definitely objectionable
6. Unusable

Table 2 shows the total durations for which the overall degradation to the re-radiated signal accorded with those grades. The durations quoted apply to the quality of the best signal available at any time, with respect to all types of impairment (i.e. fading, co-channel interference, impulsive interference and precipitation static). Table 2 also shows an estimate prepared by Transmitter Department of the overall quality of the signal that would have been radiated had the new Yagi array not been available.

TABLE 2

Impairment, Due to All Causes, of the Signal Radiated from Les Platons

Subjective Grade	Total number of programme hours	
	With new Yagi array	Without new Yagi array
1. Imperceptible	1947·4	1887·1
2. Just perceptible	32·6	31·6
3. Definitely perceptible	20·0	49·9
4. Somewhat objectionable	3·8	29·6
5. Definitely objectionable	0·2	4·4
6. Unusable	0	1·4

Similarly Table 3 shows the durations of the grades of impairment due to co-channel interference alone.

TABLE 3

Impairment, Due to Co-channel Interference, of the Signal Radiated from Les Platons

Subjective Grade	Total number of programme hours	
	With new Yagi array	Without new Yagi array
1. Imperceptible	1971·8	1929·0
2. Just perceptible	18·6	20·1
3. Definitely perceptible	11·9	33·9
4. Somewhat objectionable	1·6	16·9
5. Definitely objectionable	0·1	3·4
6. Unusable	0	0·7

The results of Table 1 show the overwhelming preference for the new Yagi array rather than the other aerials. Tables 2 and 3 show that, as would be expected, the new aerial gave greater improvement with regard to co-channel interference than with regard to total interference from all causes but that, nevertheless, the new aerial provided a considerable reduction in interference of all kinds. For example, it reduced the total duration of interference of grade 4 or worse from 35 hours to 4 hours over the six-month test period.

It is understood that the facility of null-slewing was seldom used. This may be because the controls can only be varied slowly compared to the rate of fading and because they are arranged so that the amplitude and phase can only be varied independently.

The combining amplifiers have proved completely trouble-free during the first twelve months of service use; this is in spite of direct lightning strikes to other structures within about 100 m from the array. Intermodulation products have not been observed on the received signals except on very rare occasions when propagation conditions on the path from North Hessary Tor become very favourable. Under these conditions, the combining amplifiers may be disconnected and the output from a single bay of the aerial connected directly to the receiver.

4. CONCLUSIONS

The new Yagi array at Torteval has brought about a great improvement to the television service radiated from Les Platons. The results of Section 3.2 show that the station staff chose its signal as a source of programme, in preference to that from all other aerials, for 99·2% of the time. The results also show that, during the six-month test period, its use reduced by about 43 hours the time for which co-channel interference was troublesome, and by about 60 hours the time for which interference of all types

was troublesome. These results have been obtained over a six-months summer period, the time of year when the most severe interference usually occurs.

It is understood that the null-slewing facility of the new array has not been greatly used. This may be due in part to difficulty in manipulating the controls but, in any case, it was usually found that the array dealt adequately with the interference without further adjustment.

The combining amplifiers have proved completely trouble-free (including immunity to nearby lightning strikes) during the first twelve months of service use. No inter modulation products were observed under normal conditions at the Torteval receiving site, but intermodulation may pre clude the use of combining amplifiers of this type if a similar re-broadcast receiving aerial is to be used at a transmitting site.

5. ACKNOWLEDGEMENTS

The full-scale embodiment, and the erection, of the aerial was carried out by Transmitter Planning and Installation Department. The performance tests described in Section 3.2 were arranged and carried out by Transmitter Department.

6. REFERENCES

1. Observations on the interference to the television trans mission from North Hessary Tor, caused by back-scatter from the sea. BBC Research Department Report No. K-129, Serial No. 1957/24.
2. PAGE, H *and* WHYTHE, D.J. 1966. Corona and precipitation interference in v.h.f. television reception. *Proc. Instn elect. Engrs.*, 1967, **114**, 5, pp. 566 – 576.

CORRIGENDA

Page 9, Fig. 11

Earth connection should be added at junction of C_6, C_7

7. APPENDIX

DESIGN AND PERFORMANCE OF THE COMBINING AMPLIFIERS

7.1. Pre-amplifiers

The circuit diagram of the pre-amplifiers is given in Fig. 11. Each pre-amplifier comprises a pair of common emitter stages, with emitter-to-base feedback through R_6 and R_7, followed by a common-base output stage. The amplifier is tuned by adjusting C_5 and C_8 (with the feedback removed by inserting C_{11}). The feedback causes the

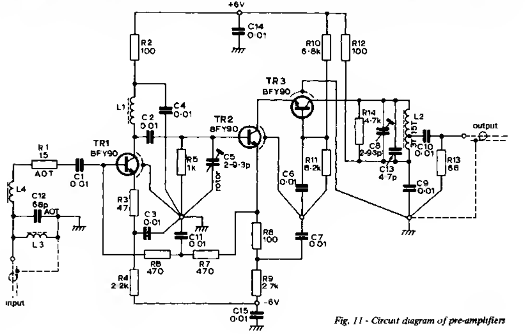

Fig. 11 - Circuit diagram of pre-amplifiers

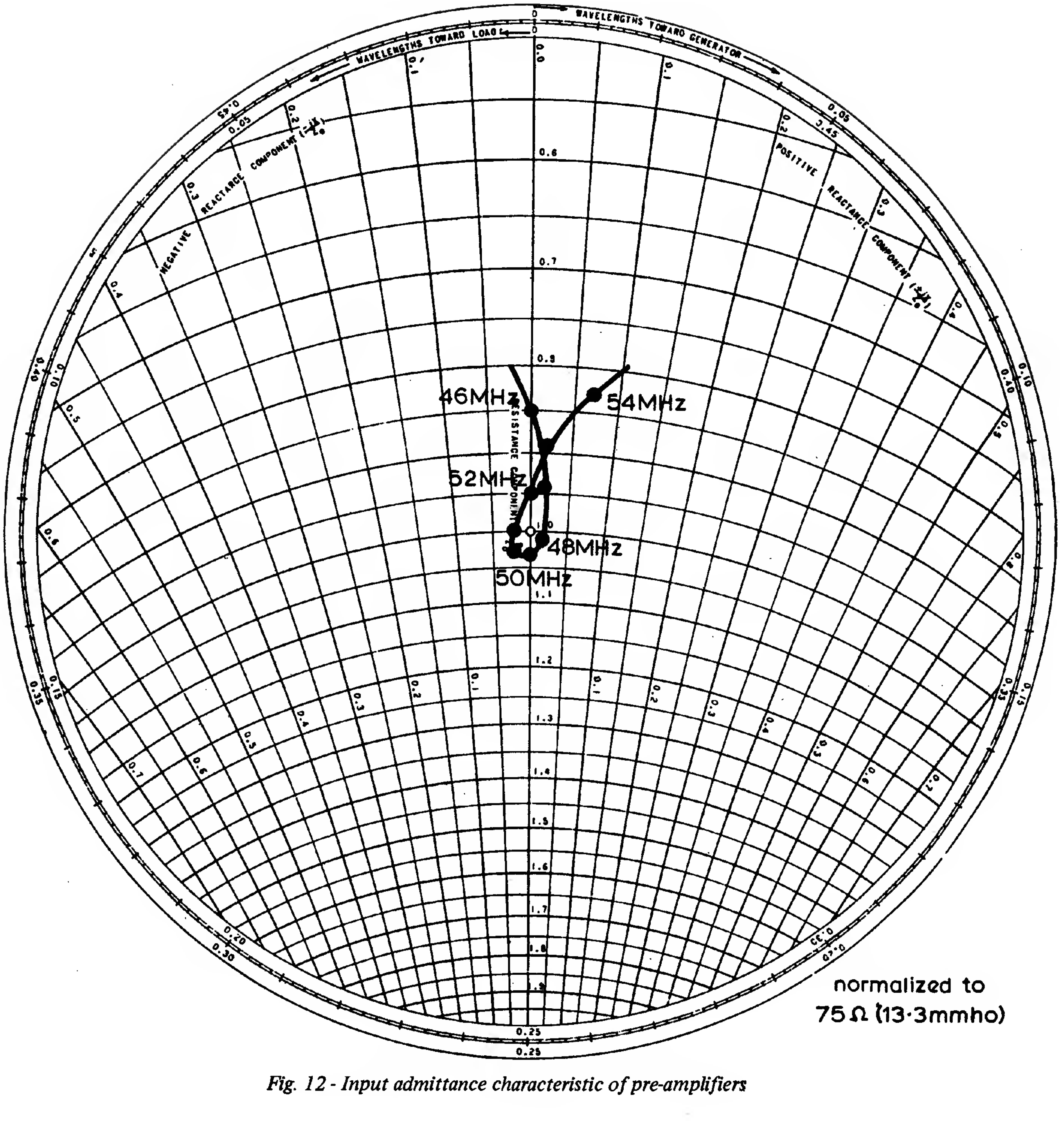

Fig. 12 - Input admittance characteristic of pre-amplifiers

input resistance of TR_1 to be about 60Ω; the value of R_1 is adjusted on test to make the overall input resistance equal to the characteristic impedance of the feeder (75Ω). L_4 is tuned to series resonance at mid-band with the input capacitance of TR_1; L_3 and C_{12} provide susceptance compensation over the band. The resulting input admittance characteristic is shown in Fig. 12, the gain/frequency characteristic in Fig. 13. The measured noise factor at 50 MHz was 3·1 dB.

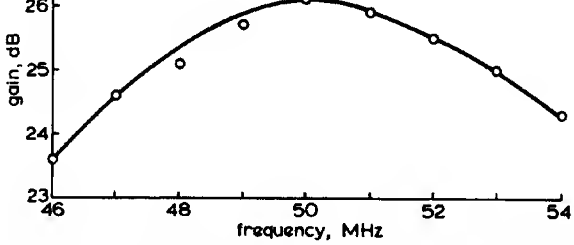

Fig. 13 - Gain/frequency characteristic of pre-amplifiers

7.2. Variable Gain and Phase Amplifiers

The variable gain and phase amplifiers were both made of similar design in order to equate their group delays. Their circuits are shown in Figs. 14 and 15. Both comprise a pair of common-emitter stages with an inter-stage network, the first stage having current feedback in order to give an input impedance of about 75Ω. For the variable-gain amplifier, the inter-stage network comprises a variable capacitive potentiometer and, for the variable-phase amplifier, a variable RC phase-shift network.

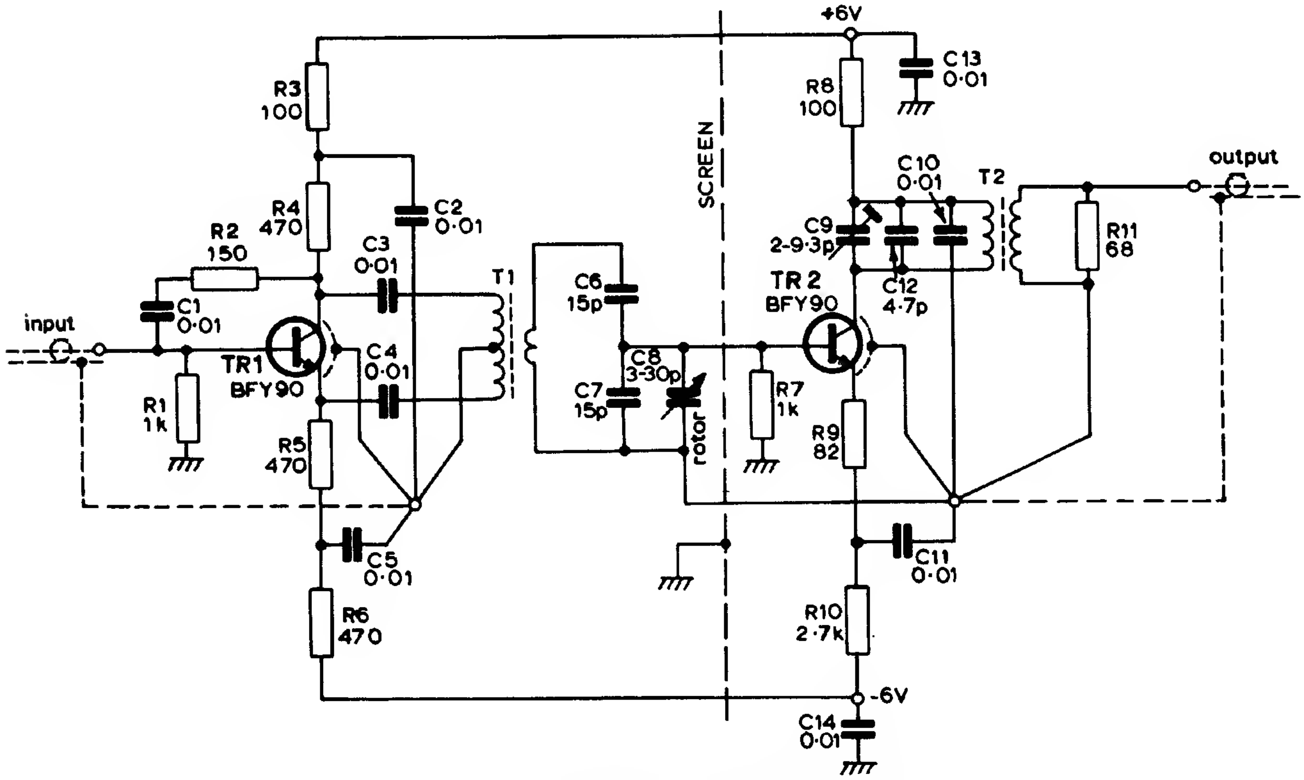

Fig. 14 - Circuit diagram of variable-gain amplifier

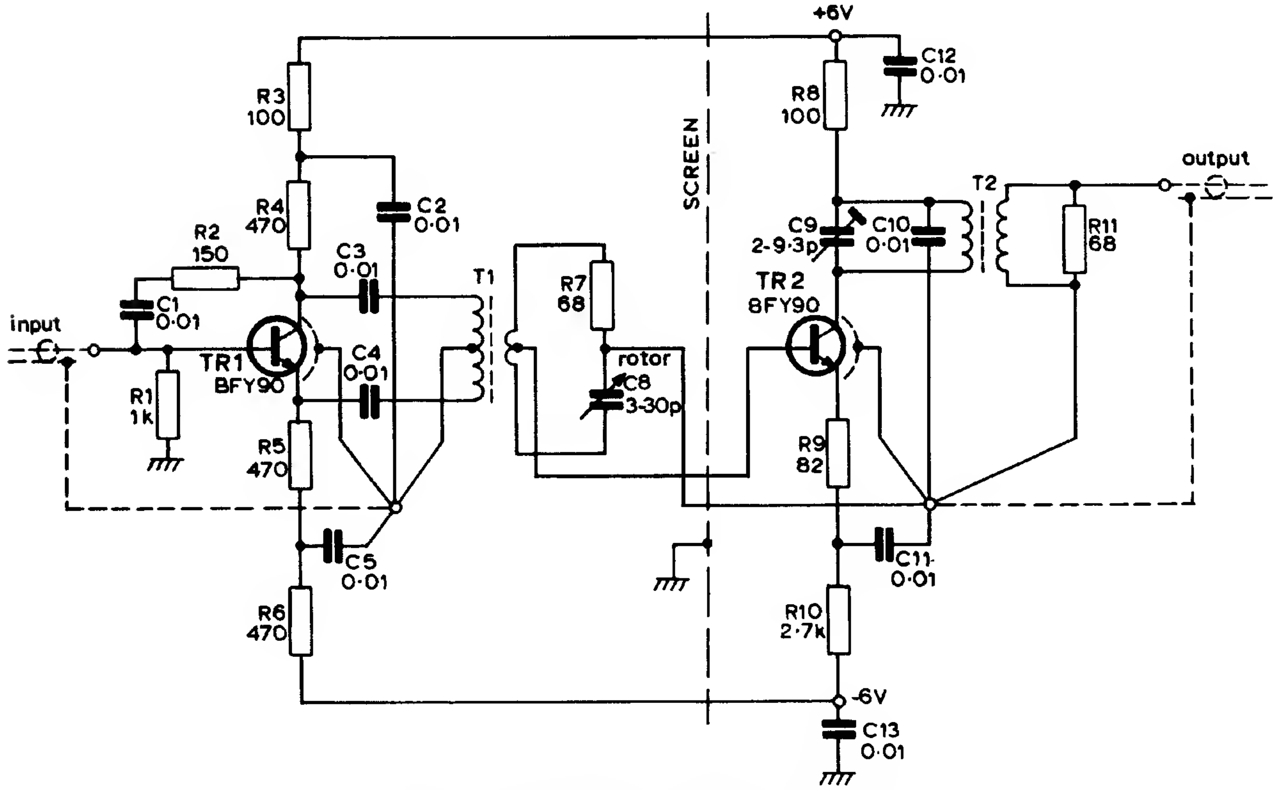

Fig. 15 - Circuit diagram of variable-phase amplifier

CORRIGENDA

Page 11, Figs. 14 and 15

Earth connections should be added at junction of C_2, C_5 and C_{10}, C_{11}

Figs. 16 and 17 show the variation of gain and phase of the two amplifiers as a function of control settings; Fig. 18 shows their gain/frequency characteristics at the extremes of their control settings.

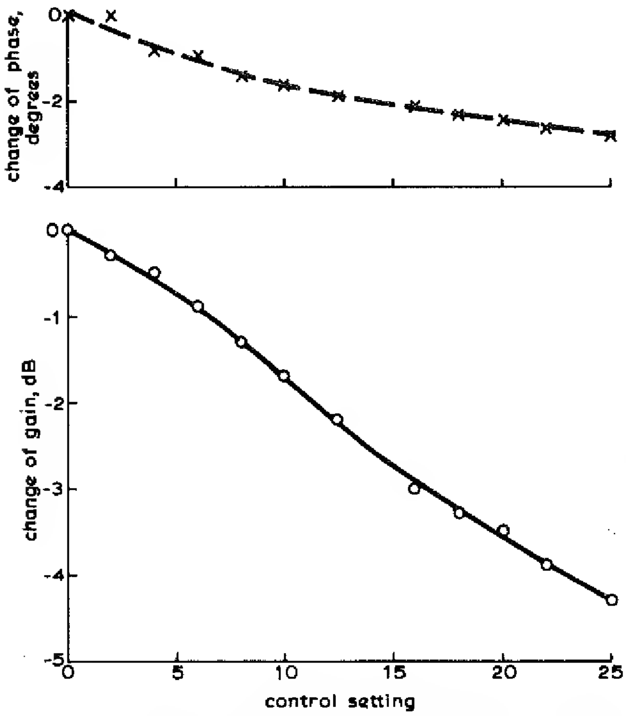

Fig. 16 - Gain and phase variation of variable-gain amplifier

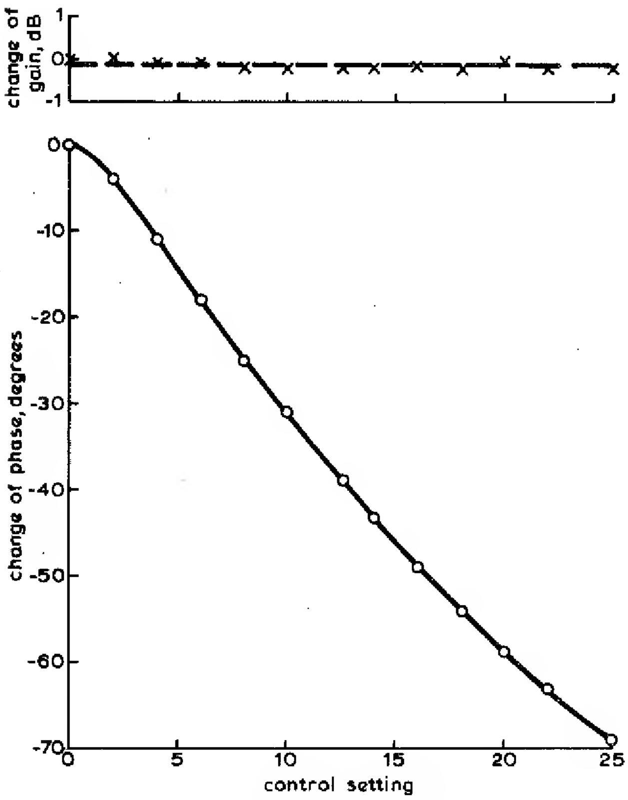

Fig. 17 - Gain and phase variation of variable-phase amplifier

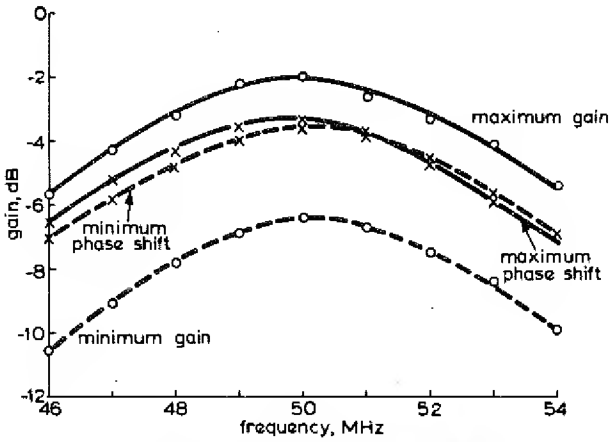

Fig. 18 - Gain/frequency characteristics of the variable gain and phase amplifiers

o Variable-gain amplifier

x Variable-phase amplifier

7.3. Buffer Amplifier

Fig. 19 shows the circuit diagram of the buffer amplifier. It comprises a pair of common-emitter stages with a common collector load.

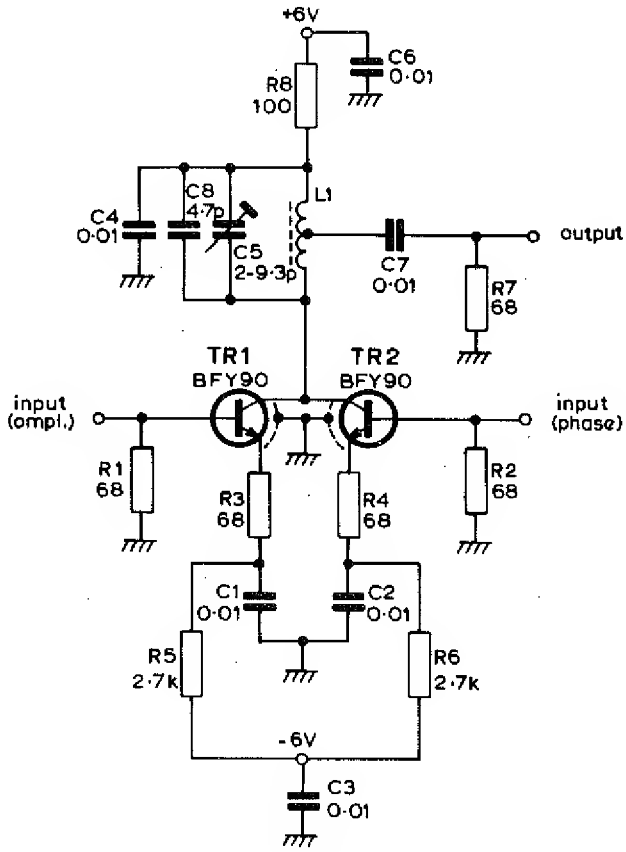

Fig. 19 - Circuit diagram of buffer amplifier

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